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Nesting behavior of the icefish *Chaenocephalus aceratus* at Bouvetøya Island, Southern Ocean

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Abstract We describe in situ observations on nesting by the Scotia Sea (or blackfin) icefish *Chaenocephalus aceratus* (Lönnberg) that constitute the first substantive evidence of egg brooding and parental care by species of the family Channichthyidae. At Bouvetøya Island six fish, all apparently male, were observed guarding egg nests at depths of 141–148 m during an ROV deployment. Eggs were laid as aggregated, round masses (~20–25 cm diameter) in shallow, circular depressions (~1-m diameter, ~20-cm depth) that were probably excavated by the parent(s) to protect the nests. The fish guardians remained tenaciously in contact with the eggs despite disturbances caused by the ROV, reacting to this threat with stress and defense behaviors. Because brooding fishes are more susceptible to population impacts from trawl fisheries, we argue that this life history should be kept in mind in designing management schemes.

Introduction

Nesting and parental care are surprisingly common, widespread, and diverse in bony fishes (Helfman et al. 1997). Although most species scatter or abandon eggs upon or after fertilization, about 90 of approximately 420 families of bony fishes include species that engage in some form of defense or manipulation of eggs and young. The extension of care beyond the fertilization stage greatly increases the probability of successful hatching and dispersal, thereby enhancing the likelihood that offspring will live to reproduce. Parental care is of great importance for demersal or adhesive eggs, which may be easily detected and consumed by foraging predators. Parental attendance often prevents such predation and enhances the health of the developing embryos by the culling of dead eggs (Helfman et al. 1997).

Among Antarctic notothenioid fishes, publications on nesting behavior are limited to the family Harpagiferidae and five species of the family Nototheniidae (Daniels 1978; Daniels 1979; Ekau 1989; Kondo et al. 1990; Konecki and Targett 1989; Rae and Calvo 1995; White and Burren 1992). Although some members of the family Nototheniidae, such as *Notothenia rossii* and *N. coriiceps* produce pelagic eggs (North 1991; North and White 1987; White et al. 1982), the laying of eggs in nests and parental guarding of the eggs may be a more common reproductive strategy among notothenioids in general.

Uniparental care of young by males is found in 36 teleost families (Blumer 1979, 1982), and biparental care occurs in most of the remaining 41 families for which the sex of the caregiver is known. In an evolutionary context, masculine guarding can be viewed as a mechanism to assure paternity (Helfman et al. 1997). Nest guarding has been observed by males of *Harpagifer antarcticus*, *Patagonotothen tessellata*, and *Lepidonothen nudifrons* and by females of *Trematomus bernacchii* (Daniels 1978; Moreno 1980; Hourigan and Radtke 1989; Rae and Calvo 1995). Whether one sex predominates as guard among the notothenioids is unknown.

Fish species that guard nests of eggs in known spawning grounds [the reproductive "hot spots" of Drazen et al. (2003)] are likely to be highly vulnerable

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to trawling because recruitment of new individuals to the stock would be impacted both by predation on orphaned nests and by disturbance of the physical and community structures of the grounds. Thus, the understanding of fish life histories is of critical importance for managing fisheries for long-term sustainability.

Chaenocephalus aceratus, the Scotia Sea or blackfin icefish, is distributed throughout the Scotia Arc Islands and at Bouvetøya Island at depths ranging from 0 m to 770 m (Iwami and Kock 1990). At South Georgia the species has been caught as bycatch incidental to the fisheries for the Patagonian toothfish *Dissostichus eleginoides*, the marbled notothen *N. rossii*, and the mackerel icefish *Champsocephalus gunnari*. Annual catches from the South Orkneys and other Scotia Arc Islands have been reported as several hundred tons (CCAMLR 2002; Kock 1992). The Scotia Sea icefish spawns large eggs (~5 mm) in the autumn. Time of spawning shows a latitudinal trend, occurring one or more months later in the more southerly South Orkney Islands and the Antarctic Peninsula region in comparison to South Georgia (Kock 1992).

The International Collaborative Expedition to Collect and Study Fish Indigenous to Sub-Antarctic Habitats cruise (ICEFISH) of 2004 (17 May–17 July) was designed to relate the evolution, eco-physiology, eco-biochemistry, community structure, and population dynamics of Antarctic notothenioid fishes to the transitional notothenioid fauna of the cool/temperate Sub-Antarctic. The cruise sampled at several island groups between Chile and South Africa, including Bouvetøya. Due to its isolation (Fig. 1), Bouvetøya has been rarely visited and even more rarely sampled. During a remotely operated vehicle (ROV) survey off Bouvetøya Island performed on 29 June, we observed adult specimens of *C. aceratus* that appeared to be brooding large egg masses deposited on the seabed. Further analysis suggested that the adults had cleared a shallow depression of benthic fauna to produce a nest in which they could guard their eggs from predation.

Materials and methods

Station and sampling regimes

As part of the ICEFISH cruise program, we conducted fishing operations from the RVIB Nathaniel B. Palmer near Bouvetøya Island between 23 and 30 June 2004. Sampling was multimodal, including Otter trawls, traps, and for characterization of the invertebrate fauna and marine habitat, an ROV system and Smith MacIntyre sediment grabs. A total of 61 specimens of *C. aceratus* were captured during 21 bottom trawl gear deployments, all within the Antarctic Convergence at South Georgia, the South Sandwich Islands, and Bouvetøya.

ROV deployments

Bottom images were obtained at Station 80/ROV1 (54°23.48′S, 03°29.24′E) by use of a HyBall ROV equipped with a JVC TK885E video camera, and the video was recorded to digital tape. The resolution of the camera permitted us to focus on objects as small as 5 mm and as close as 15 cm from the substrate. Most deployments lasted approximately 2 h.

Sex of the guardians

Olsen (1955) suggested that the second ray of the first dorsal fin of *C. aceratus* is larger in males than in females and possibly represents a sexual dimorphism. To test this hypothesis, we calculated the ratio of the second ray of the first dorsal fin height (SRFDFH) to the standard body length (BL) from Olsen's data (Olsen 1955, Table 3 therein). The significance of this morphometric parameter was evaluated by one-way ANOVA.

Results

During the ROV survey near the northeastern sector of Bouvetøya Island (29 June 2004) (Fig. 1), we obtained a

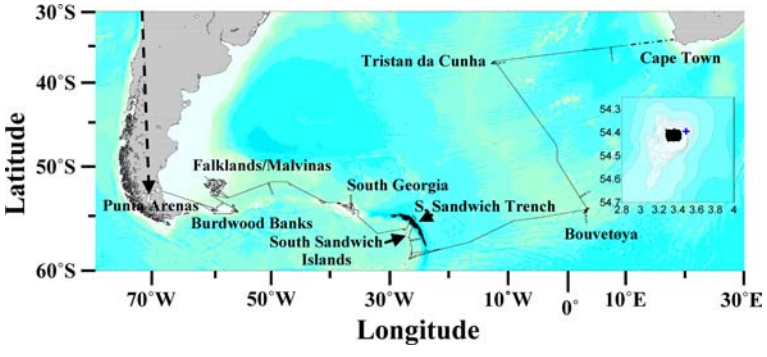

Fig. 1 The ICEFISH cruise track. The cruise departed Punta Arenas, Chile on 17 May 2004 and terminated in Cape Town, South Africa on 17 July 2004. Note Bouvetøya's isolation. The *inset* shows the location of Station 80/ROV1 (+)

video sequence of six *C. aceratus* adults, each in close proximity to large masses of fish eggs deposited on the sea bottom. The in-situ observations were made at depths between 141 m and 148 m. Analysis of the ROV images allowed us to describe the nesting behavior of the icefish species, and the general seafloor topography and epifauna in the vicinity of the fish eggs deposits, including the impact of the nesting activities. Complementary information on the fish and benthos communities and the seabed sediment structure was obtained from samples gathered by bottom trawls and grabs.

Habitat description

The undisturbed sediment surface was fine mud to silt and included pebbles and gravel of volcanic origin. The substrate was extensively covered by macrobenthic organisms. A qualitative visual survey revealed a community dominated by calcareous reefs composed of polychaetes of the family Serpulidae (Fig. 2). Crinoids were the most conspicuous element of the fauna (perched atop any topographic high point), followed by the seastars *Macroptychaster accrescens*, *Porania antarctica*, and *Cuenotaster* spp. Anemones, sabellid polychaetes, and brittle stars (*Ophionotus* spp.) were also present. Sponges or sponge spicules were not observed in the substrate that we surveyed.

Nesting behavior

At least six egg masses and guarding fish were observed during the ROV operations. The eggs were laid in shallow depressions in the bottom (~1-m diameter by 20-cm depth) in areas cleared of macrobenthic organisms, possibly by actions of the fish. Moreover, several nests were surrounded by low ridges, which suggested that the fish dug the depressions by pushing the local matrix aside. [It is possible that the sites are re-occupied and re-worked each year (not necessarily by the same individuals), which would account for the relative absence of large rubble.] The eggs were typically aggregated as a circular flattened mound 20–25 cm in diameter, with a dimple-like indentation in the central part (Fig. 3a). They appeared to be deposited on a combination of volcanic gravel and serpulid worm tubes. We hypothesize that the depressions containing egg masses were sculpted by the *C. aceratus* adult to provide better protection from high currents, which were obvious from the water flows impacting the abundant crinoids. The rock and tube aggregate beneath the egg masses may provide vents to ensure adequate aeration of the developing embryos.

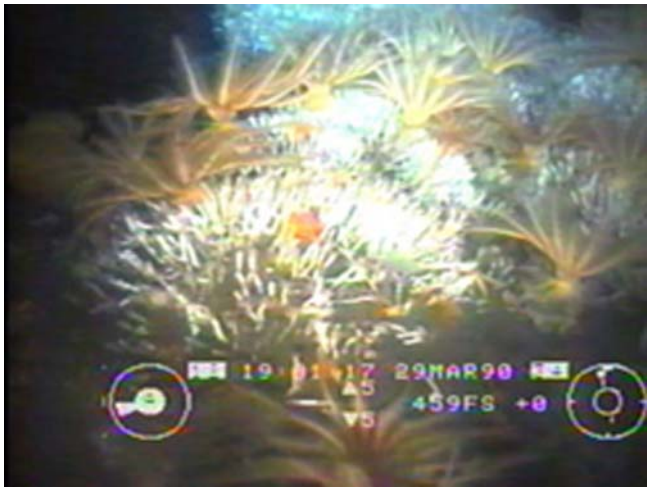

Fig. 2 Macrobenthic epifauna of the study site. Note that the date/time stamps in this and subsequent images are incorrect. Set originally to the date and time of ROV deployment (29 July 2004, ~22:00 local time), the ROV defaulted in error to 29 March 1990

Chaenocephalus aceratus spawns yellow–orange eggs of about 5-mm diameter around March–May at South Georgia (Kock and Kellermann 1991) and April–May at the South Orkney Islands (British Antarctic Survey, unpublished data). If *C. aceratus* at Bouvetøya are similar, then the egg masses were probably spawned up to 2–3 months before our observations. From what is known of *C. aceratus* at South Georgia and the S. Orkney Islands a single female lays between 9,000 and 18,000 eggs comprising approximately 25% of its total prespawning mass (Kock and Kellermann 1991).

The behavior of the fish associated with the egg masses suggested that these individuals were providing parental care to their nests. (For a short video, see http://www.icefish.neu.edu, click Photo and Video Gallery tab.) The fishes remained tenaciously in contact with the egg masses, despite the disturbances created by ROV operations (including in one case direct contact of the ROV with the fish), and assumed alternatively "C-shape" (stress and defense) (Fig. 3b) and "tripod" (quiet) postures. Robilliard and Dayton (1969) described the characteristics of the C-shaped defense posture of the icefish *Pagetopsis macropterus*, and Ekau and Gutt (1991) described a similar posture (S-shaped) in notothenioid fishes as a typical reaction to ROV lights.

Sex of the guardians

Each of the guarding individuals possessed a relatively high first dorsal fin, which appears to be a common sexual dimorphism indicative of the male of the species (Olsen 1955). To test the hypothesis that this character differentiates male and female specimens of *C. aceratus*, we reanalyzed Olsen's original data set (Olsen (1955), Table 3 therein). The ratio between the second ray of the first dorsal fin height (SRFDFH) and the body (standard) length (BL), when analyzed by ANOVA, showed that males and females were significantly different (mean for males = 0.41 ± 0.031 SD, $n = 18$, females = 0.33 ± 0.028, $n = 7$; $P < 0.001$). Furthermore, application of a *t* test to the two sex groups showed that

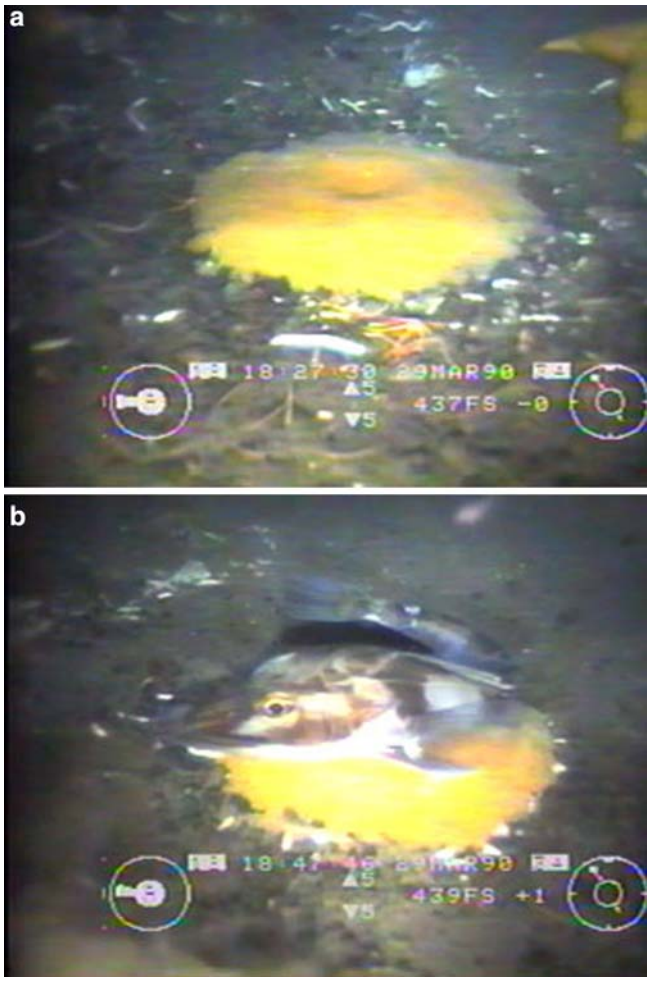

Fig. 3 *Chaenocephalus aceratus* nest structure and nest tending. **a** Untended *C. aceratus* egg mass. Note that the eggs were aggregated in a circular flattened mound (diameter ~20–25 cm) with a dimple-like indentation in the center. The egg mass appeared to be deposited on a combination of volcanic gravel and abandoned serpulid worm tubes. **b** Adult *C. aceratus* individual 1 guarding an egg mass. Note the C-shaped defense posture of the guard

the SRFDFH/BL difference was unrelated to the specimen size ($P << 0.001$, two-tailed t test assuming equal variance). Therefore, we conclude that this metric may be used to predict the sex of individual *C. aceratus*.

The SRFDFH/BL ratio of *C. aceratus* individual 1, 0.442, fell within the range of values that we calculated for males from Olsen's samples. Although the remaining specimens were not favorably oriented for this analysis, their high dorsal fins suggest that they, too, were males.

We also note that the dark cheeks and brilliant white subopercula of the six specimens were consistent with our hypothesis that the guardians were mature males.

Discussion

This report provides the first substantive evidence of nest guarding in icefishes. Parental care is a quite widespread behavior among fishes, and our report, coupled with previous reports of nesting by other notothenioid families, suggests that it may be a relatively common phenomenon in species of the suborder. Antarctic notothenioid fishes grow relatively slowly, reach reproductive age in 5–7 years, and invest large amounts of energy in the production of large, slowly developing eggs/embryos (Everson 1997; Kock 1992; Everson et al. 1996). Given the evidence for parental care of *C. aceratus* egg masses in discrete spawning grounds (H.W. Detrich, unpublished observations), this report emphasizes the importance of careful evaluation of life history strategies when considering the methods appropriate for opening fisheries for Antarctic icefish species. We suggest that a multinational effort be made, within the framework of the Antarctic Treaty and its consultative organizations, to map the spawning territories of *C. aceratus* and to protect them as marine sanctuaries (Roberts et al. 2003).

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